Safeguards Approaches-MOX fuel Fabrication Plants

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Motivation

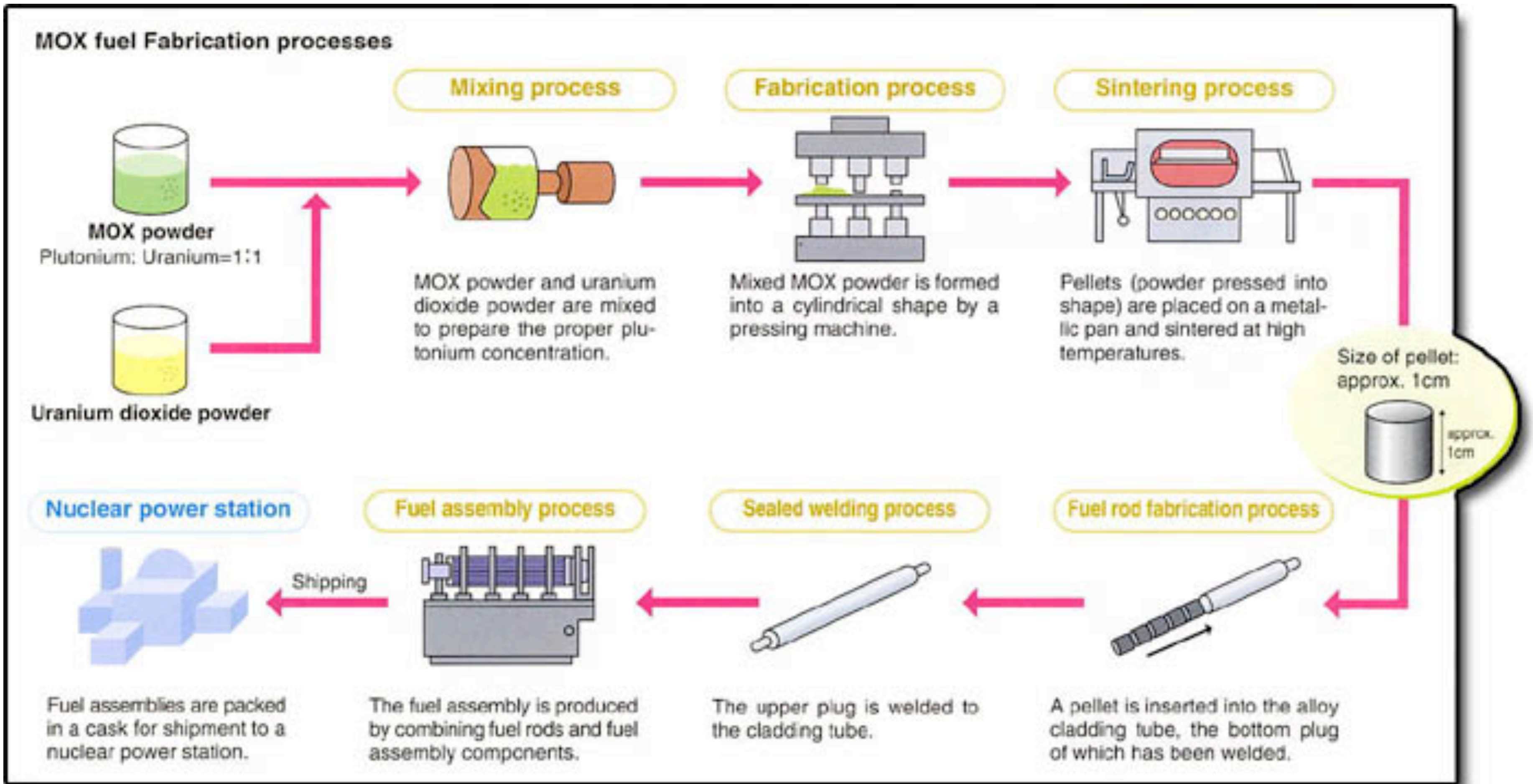
- **Mixed Uranium-Plutonium Oxides are Direct Use materials**
  - Both plant input & output high attractiveness
- **No self-protecting levels of radiation**
- **Bulk material (powder, pellets) – no item accountability in most of plant**
- **Large Scale plants pose greater challenges**
  - For a MOX plant that has an annual throughput of 8 metric tons of plutonium, one significant quantity of plutonium (8 kg) represents 0.1% of the plutonium throughput
- **Expanded nuclear energy worldwide & expanding interest in "closing" the conventional nuclear fuel cycle**
  - Nuclear energy self-sufficiency for non uranium rich states (Japan, France)

Existing/Proposed Facilities under International Safeguards Auspices

FACILITY	STATE	CAPACITY (TMOX/YR)	STATUS
PFFF	Japan	10	Operating
PFPF	Japan	5	Operating
BN-MOX / FBFC-MOX	Belgium	40	Closed (2006)
Siemens MOX	Germany	35	Canceled
MELOX	France	195	Operating
Sellafield - MOX	United Kingdom	40 (orig. 128)	Operating
J-MOX	Japan	130	Planned
MFFF	US	n/a[1]	Planned

1. MFFF is not a commercial plant; it is designed to convert 3.5 MT of surplus weapons Pu to MOX under a bilateral agreement with Russia

Generic Process Flow Sheet



Safeguards at MOX Plants

- DIE/DIV
- Containment/Surveillance Measures
- Nuclear Material Accountancy
- Near Real Time Accountancy
- Additional Protocol/Integrated Safeguards
- Intrusiveness & Commercial Considerations

Design Information Examination and Verification

- **MOX plants have tremendously long lead times (~15-20 years)**
  - J-MOX was announced publically in 2005, commercial operation in 2015
- **Ample opportunity for early involvement of International Atomic Energy Agency**
- **Early IAEA Assessment of facility plans**
- **Ongoing verification during construction**
- **Focus on: consistency of processing capacity, un-declared take-off points**
- **MOX facilities are dry process facilities: easier than reprocessing**
- **MOX facilities cannot effect element/isotopic separations**

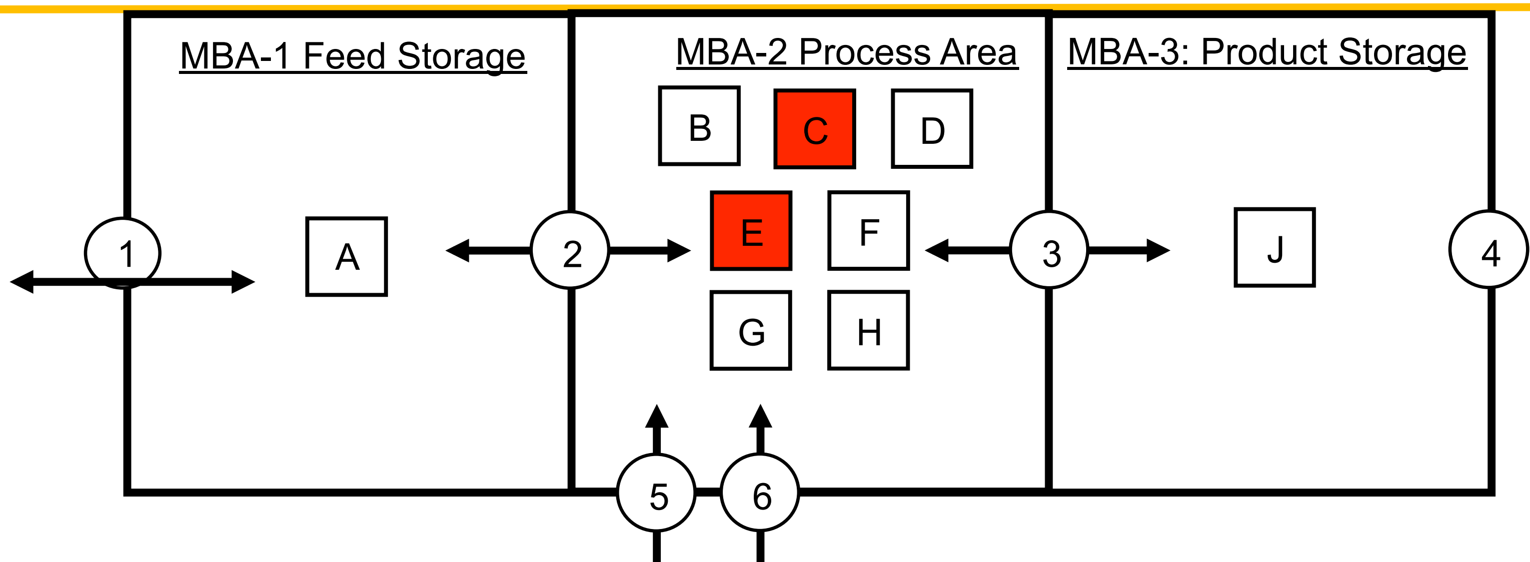
Containment & Surveillance

- **Primary use in feed & product stores**
- **Dual C/S: qualitative radiation sensor and video data**
- **In feed**
  - Record canister ID
  - Monitor arrival/departure of canisters
  - Determine if canisters are full or empty
- **In product stores**
  - Record finished fuel assembly ID
  - Monitor arrival/departure of assemblies
  - Determine if radiation pattern consistent with declaration

Material Balance Areas for a MOX Plant

- **Accountancy heavily reliant on nondestructive assay measurements**
- **Three MBA structure commonly used:**
  - Feed/Storage
  - Process Area
  - Product Storage
- **Feed Storage needed to separate Shipper/Receiver Differences from process area material –unaccounted-for (MUF) in the process area**
- **Product storage is only area of “item” accountability – finished fuel assemblies**
- **Transfers between MBAs are key measurement points (flow)**
- **Inventory measurement points within an MBA are also required**

Nominal Key Measurement Points

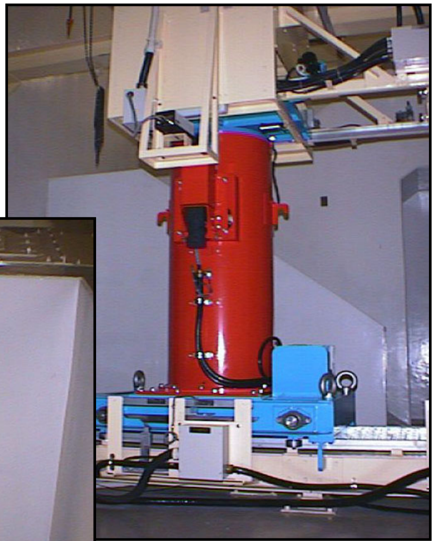


FKMP	1	Receipt/Shipment of Feed MOX Powder
FKMP	2	Transfer of Feed MOX powder between MBA1 and MBA2
FKMP	3	Transfer of Product Fuel Assembly between MBA2 and MBA3
FKMP	4	Shipment and Receipt of Product Fuel Assembly
FKMP	5	Receipt and Shipment of UO2 powder, UO2-Gd rods, U metal
FKMP	6	Transfer and shipment of Solid Waste, analytical samples
IKMP	A	MOX Canister Temporary Storage Area
IKMP	B	U02 Powder Storage Area
IKMP	C	Powder preparation process
IKMP	D	Scrap Treatment Process
IKMP	E	Pellet Fabrication Process
IKMP	F	Fuel Rod Fabrication Process
IKMP	G	Analytical Laboratory
IKMP	H	Solid Waste Storage Area
IKMP	J	Fuel Assembly Storage Area

Nuclear Material Accountancy Systems-Feed (FKMP 1)

Improved plutonium Canister Assay System for Rokkasho Reprocessing Plan MOX Product (36 kg MOX) Installed in 3/2004

- Neutron based; supplemented with high resolution gamma
- Full incoming canisters, empty canisters leaving
- Continuous, unattended mode
- Bias Defect Accuracy (<0.8%)

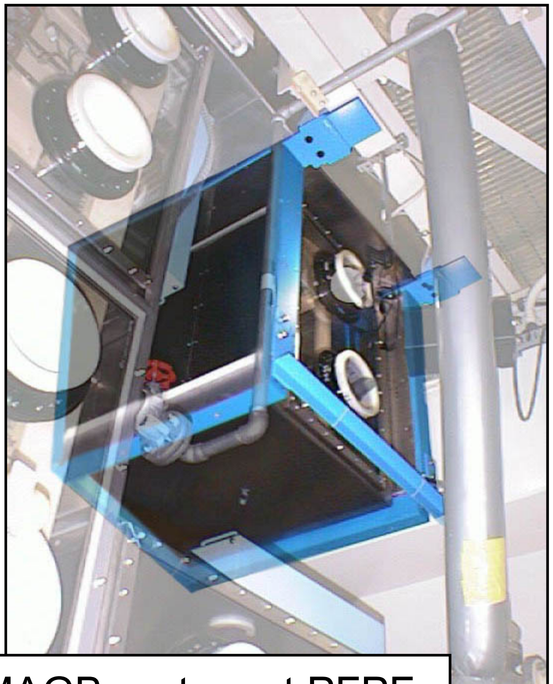


Plutonium Canister Assay Systems PFPF facility

Powder/Pellet Process Areas

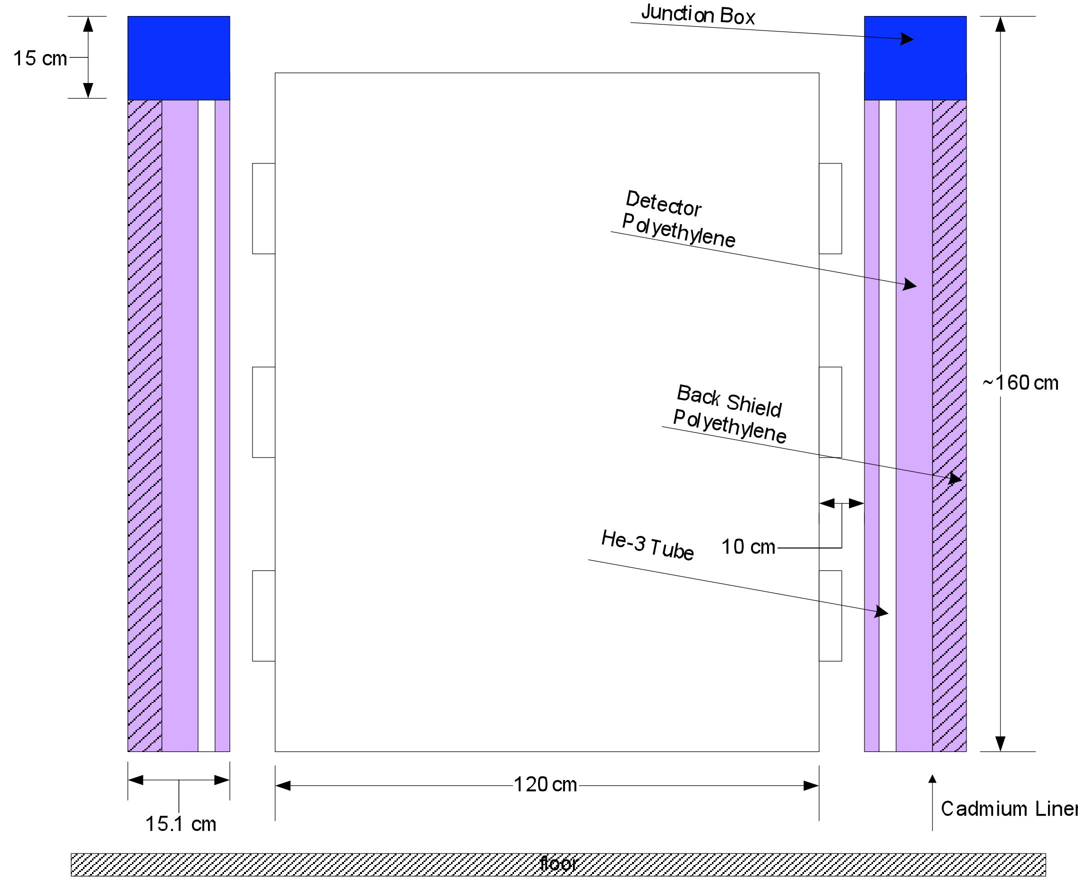
- **Operation declaration are weigh-in weigh-out (“by difference”)**
- **Inspectorate challenges**
  - Verification of in-process material during inspection (IKMP)
  - Verification of operator declaration
  - Determination of residual material left in glove box (hold-up)
- **Material Accountancy Glove Box (MAGB) systems**
  - Installed on weigh in/out point for each glove box line
  - Measures containers of powder or pellets (cans, trays)
  - Continuous unattended mode
  - Inspectorate verification with neutron gamma instruments & camera
  - Verify inventory and declaration
  - FKMP 2, IKMP C,D,E
  - Uncertainties of 2-5%
  - Challenges: Variety of containers, short measurement time, background & detection limit on empty returns

MAGB Systems



MAGB system at PFPF

Monte Carlo Model of MAGB



Hold-up Measurements

- **Huge challenge in high throughput facilities**
- **IKMP C and E**
- **Traditional method is to stop operations to perform measurement**
  - Very disruptive for commercial operations
  - Portable neutron slabs used in overlapping positions to assay each glove box
    - Very time consuming
  - High Purity Germanium Hold-up measurements
    - Even more time consuming
    - Careful corrections for self-attenuation & process equipment attenuation needed to not bias results low
  - Attended measurement – requires full time inspector presence
- **Area of active development (Glove box Unattended Assay & Monitoring system (GUAM)**

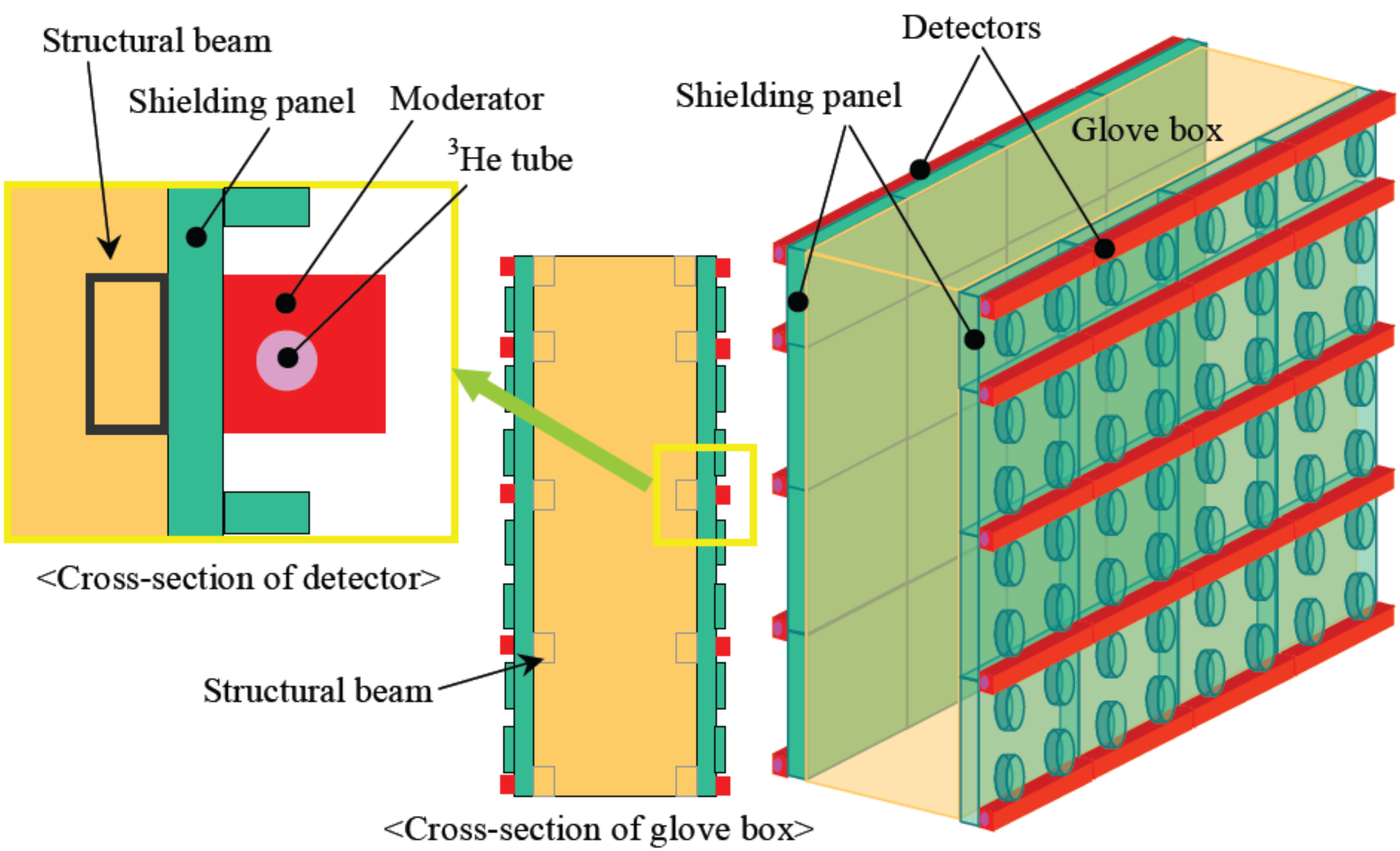
Hold-up -SBAS

- **Super Glove box Assay System (SBAS)**
- **Uncertainty: ~10%**
- **Dynamic range: few 10 g to 10 kg**
- **Deployment: 1x/year during Physical Inventory Verification**
- **Challenges:**
  - Background rates
  - Background determination
  - Hold-up distribution

New Hold-up Developments: GUAM

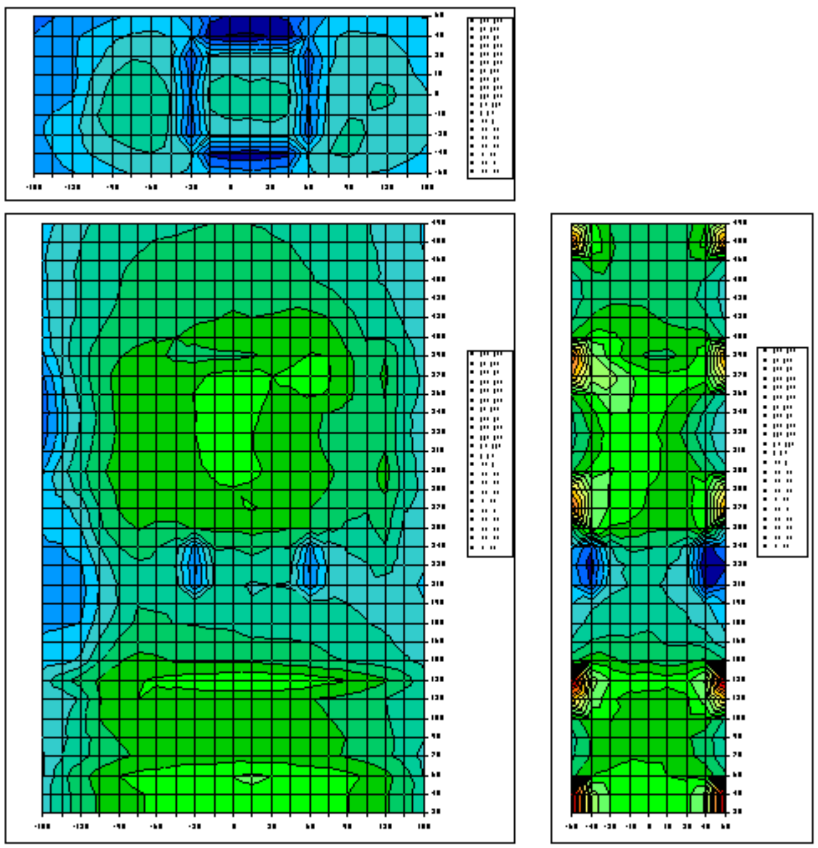
- Proposed for the large J-MOX plant
- Neutron detectors permanently installed in glove box shielding for powder & pellet processing areas
- Continuous unattended hold-up assay
- Determine hold-up on non-operating (third) shift every night, not just at inventory inspection time
- Proposed as joint operator-inspector equipment
- Monte Carlo design optimization on individual glove box basis
- Total uncertainty ~8% (partial defect)
- Qualitative “patterns’ during operating shifts

Hold-Up - GUAM

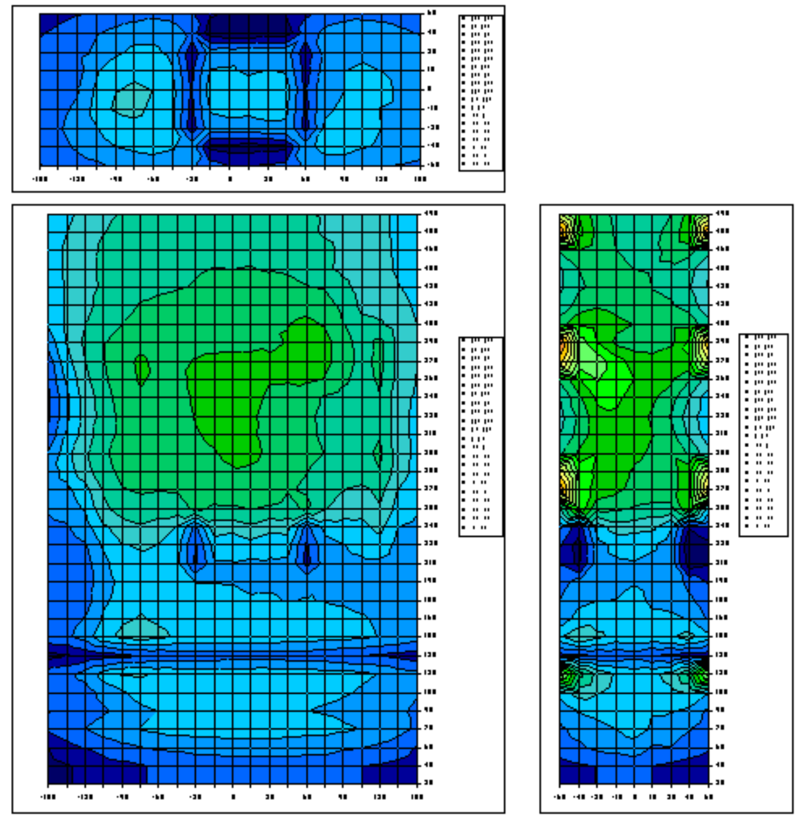


Structural beam
Shielding panel
Moderator
^{3}He tube
<Cross-section of detector>
Structural beam
<Cross-section of glove box>
Detectors
Shielding panel
Glove box

Monte Carlo Optimization of GUAM*



Singles Counts – all detectors



Singles Counts – Row 1 removed

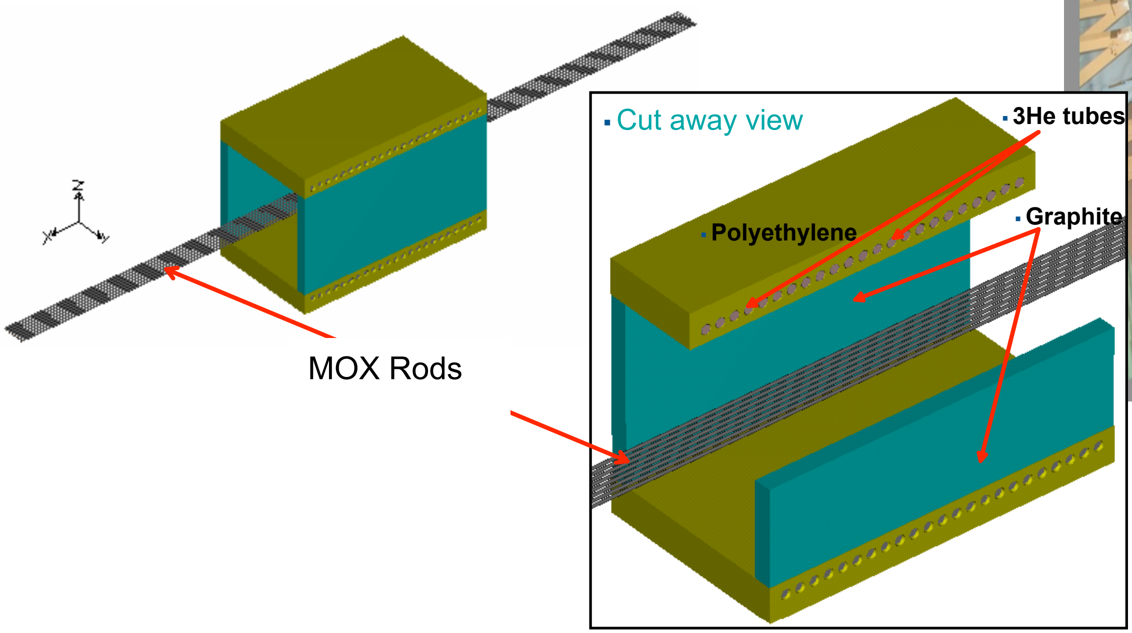
*Work of student Cory Freeman

Fuel Rod Fabrication

- **As pellets are fabricated into rods, move from bulk material to item accountability (pin, pin tray, or storage magazine)**
- **Typically neutron systems are used to establish accountancy values**
- **Continuous unattended operation**
- **High resolution gamma also done**
  - Last chance to verify isotopics on each pin (assembly interior opaque to gamma)
- **Facility layout determines type/number of nondestructive assay systems**
- **Need Pu/length and active length verification**
- **Uncertainty ~2-4%**
- **FKMP 3, IKMP F**

Fuel Pin Tray and Magazine Counters

Monte Carlo Design for Pin Tray Counter



FPAS at PFPF

Finished Fuel Assemblies

- Typically neutron systems are used to establish accountancy values
- Measurement of 100% of finished assemblies
- Facility layout determines type/number of nondestructive assay systems (separate collars for PWR versus BWR assemblies)
- Need Pu/length and active length verification
- Uncertainty: bias defect level (0.8%) to ~2%
- FKMP 3 and 4, IKMP J

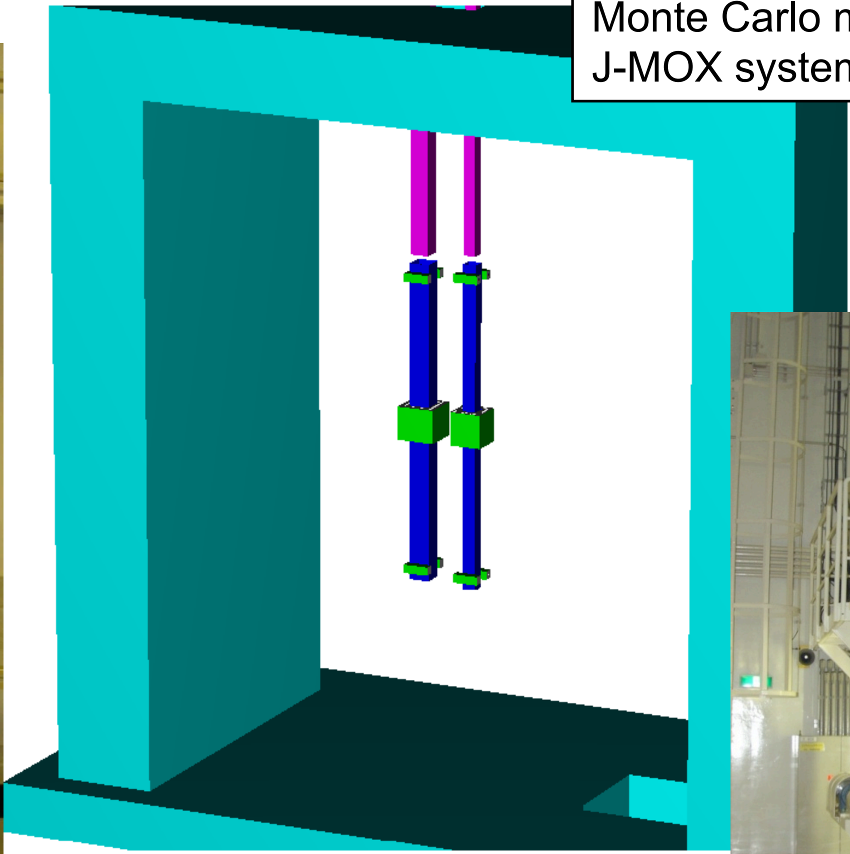
Inventory Sample Measurements

- **Nondestructive assay (neutron & gamma) systems long use to supplement analytical laboratory capability**
- **FKMP 6, IKMP G**
- **New target uncertainties (<0.5%) would expand replacement of destructive analysis with NDA**
  - Less waste, cost, time & personnel exposure
  - Less need for plutonium reference spike materials
- **Traditional attended mode**
- **Potential for continuous unattended mode installed around glove box port**

The AVIS is designed for J-MOX sample; t target uncertainty of 0.5%

Finished Fuel Assemblies

PWR Collar and two end forks for J-MOX



Monte Carlo model of J-MOX system

The Finished Fuel Assembly System (FAAS) at PFPF

Waste Measurements

- Measurement of all waste streams very important to eliminate potential diversion paths
- Typically neutron-based nondestructive assay systems; may be supplemented with gamma
- FKMP 6 and 7; IKMP H
- Uncertainties ~5-15% depending on size of container and waste matrix
- Typically attended mode operation

Commercial drum system at PFPF

Near Real Time Accountancy (NRTA) Models

- **NRTA provides a snapshot in time of material quantities and distributions**
  - Under normal plant operating conditions
  - Balance drawn at regular intervals (~ 5-15 days for large scale plant)
- **Successive snapshots used track MUF through time**
- **The quality of an NRTA balance driven by the uncertainties in the inventory systems (for example MAGB, GUAM)**
  - Key is operator's system for declarations
- **NRTA is essential for safeguards any large-scale plant**
- **PFPF piloted NRTA for MOX fuel fabrication plants**

Additional Protocol

- **Adoption of the AP per se does not necessarily reduce the safeguards equipment required at a given facility**
- **It can provide additional assurance of peaceful intent**
  - Very important for large-scale facilities
- **Complementary access, especially during MOX plant construction**
- **Environmental sampling**
  - Most useful is can do “baseline” sampling prior to start of operations

Commercial Considerations

- **All plants typically have an annual shutdown for operator inventory / maintenance**
  - Coordination of safeguards Physical Inventory Verification
- **Any additional shutdowns are disruptive & costly**
  - Incentive for continuous unattended accountancy systems
- **Any retrofit of safeguards required system are costly and awkward**
  - Incentive for early involvement of safeguards personnel

Recommended Practices

- Early Involvement of safeguards authorities
- Bias Defect capability in verification of transfers (inputs & outputs)
- All streams measured -no uncharacterized streams (and potential diversion paths)
- Key process point NDA for real-time inventory to support NRTA
- Partial Defect capability for hold up measurements
- Bias Defect capability for small sample measurement
- Onsite analytical capability
- Integrated Information System
- Process Monitoring –additional measures
- Additional Protocol State

R&D Areas

- Improved hold up measurements
- Improved nondestructive assay of small samples (replacement of destructive chemical analysis)
- Expansion of Monte Carlo modeling in design phase
- Process modeling & NRTA
- Methodologies to leverage Additional Protocol and Integrated Safeguards

- A 60 t/yr commercial MOX fabrication plant was planned at Zheleznogorsk (the site of the ADE2 military plutonium production reactor which is due to be shut down in mid 2009). Another MOX plant for disposing of military plutonium is planned at Seversk (Tomsk-7) in Siberia, to the same design as its US equivalent. (Seversk had the other two dual-purpose but basically military plutonium production reactors, totalling 2500 MWt. One of these - ADE4 - was shut down in April 2008, the other - ADE5 - in June 2008.) A pilot MOX plant is at Mayak.